

EXPERT SYSTEM DEVELOPMENT METHODOLOGY (ESDM)

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ABSTRACT

The Expert System Development Methodology (ESDM) provides an approach to developing expert system software. Because of the uncertainty associated with this process, an element of risk is involved. ESDM is designed to address the issue of risk and to acquire the information needed for this purpose in an evolutionary manner. ESDM presents a life cycle in which a prototype evolves through five stages of development. Each stage consists of five steps, leading to a prototype for that stage. Development may proceed to a conventional development methodology (CDM) at any time if enough has been learned about the problem to write requirements. ESDM produces requirements so that a product may be built with a CDM. ESDM is considered preliminary because it has not yet been applied to actual projects. It has been retrospectively evaluated by comparing the methods used in two ongoing expert system development projects that did not explicitly choose to use this methodology but which provided useful insights into actual expert system development practices and problems. This fiscal year, the methodology will be field-tested by applying it to two pilot projects.

INTRODUCTION

An expert system is a computer system that simulates, to the extent possible or practical, the way human experts solve cognitive problems, i.e., those for which no algorithm is known to solve the problem, but that are routinely solved by a domain expert using rules of thumb or heuristics. The task of developing an expert system is, therefore, to acquire information from the domain expert as to how the cognitive tasks are performed and then model the information in a form suitable for the computer. Because of the uncertainty associated with this process, an element of risk is associated with developing expert systems. ESDM has been designed to address the issue of risk and to acquire the information needed for this purpose in an evolutionary manner.

Note that it is not possible to develop specifications for an expert system before the expert's reasoning processes have been analyzed. This lack of specifications presents the manager with special problems in controlling an expert system development project. These problems are addressed in ESDM.

Analyses reveal differences between expert systems and conventional software development. Compared to conventional development, the expert system life cycle more nearly resembles rapid prototyping. The major differences between the expert system life cycle and the rapid prototyping of conventional development are

- Greater uncertainty in feasibility and suitability of the problem to an expert system implementation

- Highly iterative nature of expert system development

The major similarity is that the system produced is a prototype. More specifically, all systems produced by ESDM are considered prototypes. ESDM does not produce any of the standard products (e.g., feasibility study, requirements analysis) that are produced for a conventional software system.

The methods used to implement expert systems differ from those used for conventional systems. However, once the uncertainty of the feasibility of an expert system is reduced to a low level (i.e., after several iterations of prototype development), it will be possible to undertake development of an expert system in a conventional development cycle and to expect it to present no more difficulty than any other system. ESDM precedes conventional development and terminates when requirements can be produced.

ESDM is intended to be applied to the development of National Aeronautics and Space Administration/Goddard Space Flight Center (NASA/GSFC) expert systems. It is based on a survey of existing methodologies and an analysis of the expert system life cycle. Dr. Barry Boehm introduced a risk-driven methodology for conventional system development in his spiral model for software development (1). ESDM, while independently generated, is also a risk-driven methodology that can be represented as a spiral model. ESDM focuses more on knowledge acquisition rather than on product development. Figure 1 illustrates the spiral nature of ESDM.

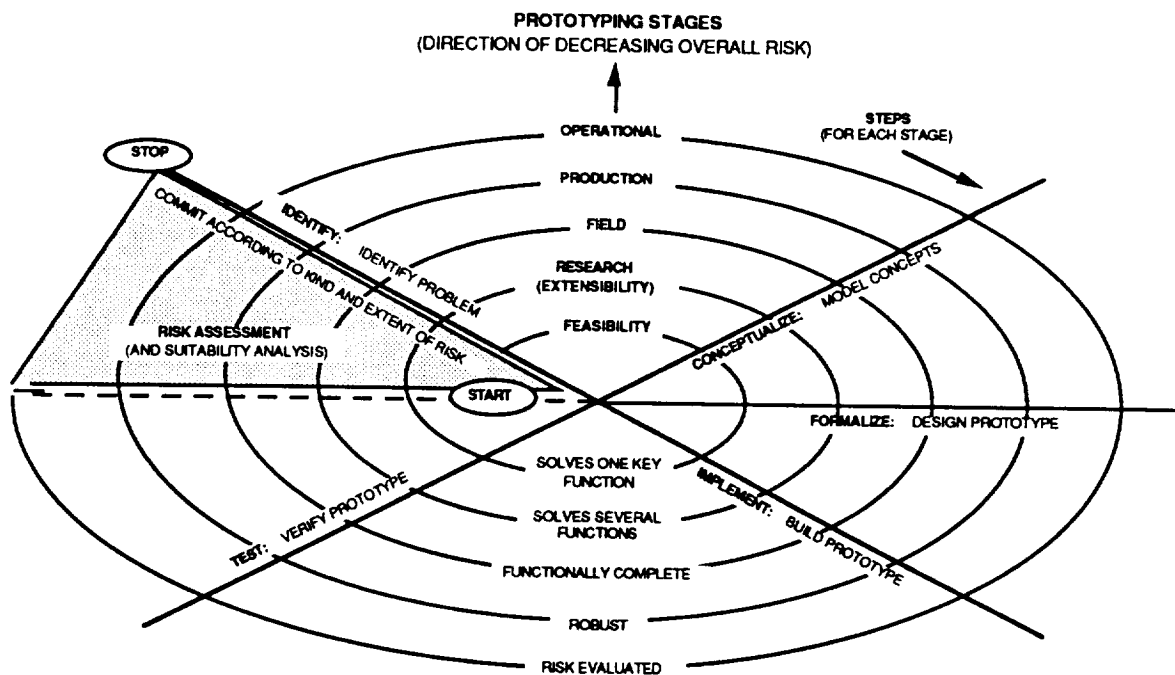


Figure 1. Spiral Model of ESDM

ESDM was developed to address large projects. Therefore, when applying ESDM to projects that are small, ESDM recommendations should be used as a guideline and adapted to suit the smaller-size project.

The proposed methodology is considered preliminary because it is untested. It is a synthesis of methodologies that have been used in conventional and expert system software development. A standard (4), a user guide (6), a reference manual (3), and a set of training materials (5) have been developed to describe the methodology. The methodology has been retrospectively evaluated by comparing the methods used in two ongoing GSFC expert system development projects: the Ranging Equipment Diagnostic Expert System (REDEX) and the Backup Control Mode Analysis and Utility System (BCAUS) (2). These projects did not explicitly choose to use the methodology but provided useful insights into actual expert system development practices and problems. This fiscal year, the methodology is being field-tested by applying it to two other GSFC expert system development projects: the Generic Expert System and the Systems Test and Operations Language (STOL) Intelligent Tutoring System (ITS). Next fiscal year, the methodology will be revised based on the results obtained.

DECISION POINTS OF ESDM

ESDM consists of five stages, each accomplished in five steps, and is geared to reducing the uncertainty of feasibility and risk in development. The ESDM life cycle is illustrated in Figure 2, which shows five decision points that determine whether work must move to one or another of the five ESDM stages. In contrast with CDM, iteration of a stage or iteration of steps within a stage may also occur. (Iteration of steps is not shown explicitly in the figure.) Higher risk issues are addressed first, and lower risk issues are addressed with each subsequent stage. Earlier stages focus on knowledge acquisition, and later stages focus on performance issues. The stages and stage products described serve as a guide and should be adapted to suit the goals and objectives of each individual project. If an alternate area is of higher risk for the project, this area is prototyped first.

In addition, there are three risk-based decisions, as follows:

- **Apply ESDM?** Are expert system development techniques suitable for the problem?
- **Stop ESDM?** Has enough been learned to decide whether to move to a CDM or to abort development? If the answer is no, then a stage is selected. A stage may be repeated or a new stage selected. If the answer is yes, the next decision is addressed.
- **Move to a CDM?** Should development move to a CDM or be aborted? Are the requirements now known, or is the risk too high to continue?

Development need not proceed through all five stages if these questions can be answered in an earlier stage. ESDM provides a metric--the Test for Application of Risk-Oriented Technology (TAROT)--to provide guidance to both managers and developers at each decision point. TAROT assists in evaluating a project for suitability to an expert system implementation and in estimating the risk involved. At the completion of the project using ESDM, a transfer to product cycle is undertaken and development continues using a CDM.

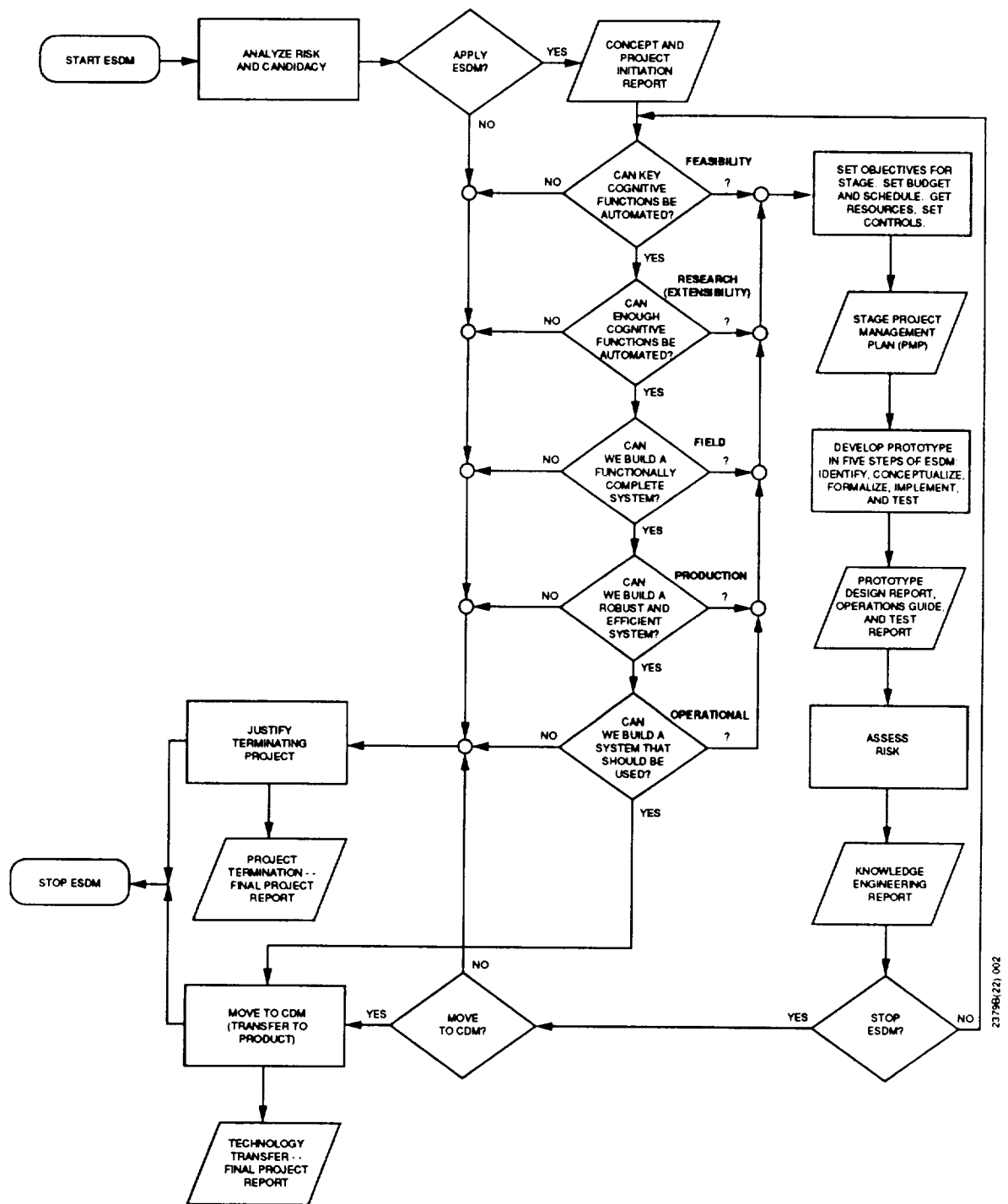


Figure 2. The ESDM Life Cycle

FIVE STAGES IN EXPERT SYSTEMS DEVELOPMENT

The proposed ESDM consists of five stages of prototype development (8). Each stage consists of five steps (7). The stages are discussed in the following subsections; the steps for each stage are discussed in the next section.

Stage 1: Feasibility

Model one or more key cognitive functions performed by domain expert.

A key cognitive function is one that is central to the overall problem the expert solves. Selecting a key function is important but not crucial because ESDM is highly iterative.

Stage 2: Research (Extensibility)

Model remaining functions.

The goal of this stage is to determine the extent to which the remaining cognitive functions performed by the domain expert can be modeled.

Stage 3: Field

Model additional functions required in the field.

This stage determines how to model the remaining cognitive functions performed by the expert. Specifically, this stage determines what combination of conventional and expert system techniques should be used to construct an automated replacement of the manual system. The goal of this stage is to design and construct a fieldable prototype that can be tested and used in a realistic setting. Performance issues have not been addressed yet.

Stage 4: Production

Address performance objectives.

This stage determines if it is possible to refine the design of, recode, or transport the system to a new host to achieve the desired scope of expertise and performance objectives. The successful production prototype is able to solve nearly all required problems and is robust and is easy to use.

Stage 5: Operational

Analyze and evaluate risks and costs of deploying the production prototype.

To reach this stage in ESDM, the development team has learned it is possible to build a prototype that simulates the functions performed by the domain expert. A knowledge acquisition process is still involved in this stage, but the focus is now on the use of the product rather than on the structure of the product.

FIVE STEPS IN EXPERT SYSTEMS DEVELOPMENT

Within each stage of expert system development, five steps are required to produce the stage prototype. These steps are highly iterative and are not necessarily performed in a simple, sequential manner--developers often work on several steps concurrently. Only in a general sense

does the work progress from one step to the next. Typically, work can and does move from a later step to an earlier step as knowledge is acquired.

Step 1: Identification

Determine problem characteristics.

In this step, the knowledge engineer identifies the problem the expert system will solve for the current stage. In the feasibility stage, the sources of expertise are identified. These sources may include one or more experts, reports, or manuals. Knowledge acquisition for the stage begins at this point.

Step 2: Conceptualization

Find concepts to represent the knowledge.

Knowledge acquisition continues in this step and includes identifying the concepts, objects the expert reasons about, the relationships between objects, control flow, constraints, and problem-solving strategies used by the expert. The knowledge is organized and modeled using a technique suitable to the problem (i.e., tables, informal rules, flow charts, hierarchies).

Step 3: Formalization

Map these concepts to formal representations based on the selected implementation tool or language.

This step involves formalizing the concepts chosen in the conceptualization step, designing the system, and selecting the hardware and software tools for implementation. The suitability of the tool or language selected for representing the problem determines the difficulty of subsequent steps.

Step 4: Implementation

Formulate rules that embody knowledge.

In the implementation step, a prototype is coded from the formal representations developed in the formalization step using the selected software tool or language.

Step 5: Test

Validate rules that embody knowledge and verify that the prototype implements the design.

This step involves evaluating the prototype's performance through testing. In the early stages of ESDM, the prototype's performance is compared against that of the domain expert. In later stages, performance issues are evaluated (e.g., robustness, speed of execution, ease of use).

TRANSFER TO PRODUCT CYCLE

An ESDM project terminates and proceeds to CDM when the risk of feasibility and use are reduced to an acceptable level and when requirements can be sufficiently defined to continue development in a sequential manner. The findings of ESDM serve as the basis for CDM and are formalized and transferred in a formal transfer review meeting. Expert system project personnel should assist in, monitor progress of, or perform the conventional product development to handle problems or issues that might arise.

An ESDM project terminates and development is discontinued if the risks of either implementation or use are considered unacceptable. A final lessons learned review meeting is conducted to preserve knowledge acquired on the project and to explain this decision.

THE ESDM PRODUCTS

The products produced at the start of an ESDM project include the following:

- **Concept and Project Initiation Report**—A high-level strategic plan for the project. It explains the results of initial risk and suitability analysis, describes the system to be automated, and justifies the project.

The products produced in ESDM in each stage of development include the following:

- **Stage Project Management Plan**—A lower level, more detailed plan than the Concept and Project Initiation Report. It is produced at the start of each stage and describes work to be completed for that stage.
- **Knowledge Engineering Report**—A summary of the knowledge acquired and the lessons learned during the stage, as well as recommendations for later stages of work.
- **Prototype Design Report**—A detailed description of the rules or other knowledge structures used in the prototype.
- **Prototype Operations Guide**—A description of prototype operation for subsequent testers.
- **Test and Evaluation Report**—A description of the test results. Evaluates the prototype.
- **The prototype.**

The products produced at the end of a project include one of the following:

- **Technology Transfer Report**—Produced following the decision to continue development with CDM. The report summarizes project findings and lessons learned, and presents recommendations for CDM development.
- **Project Termination Report**—Produced following the decision to abort development. The report justifies this decision, summarizes lessons learned, and documents results of knowledge acquisition.

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REFERENCES

1. Boehm, B. W., "A Spiral Model of Software Development and Enhancement," IEEE Computer, May 1988, pp. 61-72
2. Computer Sciences Corporation, Expert System Development Methodology: Framework for Evaluation of ESDM, March 1989
3. Computer Sciences Corporation, Expert System Development Methodology Reference Manual, Revision 1, DSTL-90-006, August 1989
4. Computer Sciences Corporation, Expert System Development Methodology Standard, Revision 1, DSTL-90-005, August 1989
5. Computer Sciences Corporation, Expert System Development Methodology Training Materials, CSC/TM-89/6091, July 1989
6. Computer Sciences Corporation, Expert System Development Methodology User Guide, Revision 1, DSTL-90-004, August 1989
7. Hayes-Roth, F., Waterman, D. A., and Lenat, D. B., Building Expert Systems, Addison-Wesley Publishing Company, Inc., 1983
8. Waterman, D. A., A Guide to Expert Systems, Addison-Wesley Publishing Company, Inc., 1986